

Wounded quark emission function in small systems

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Michał Barej, AB, Paweł Gutowski,
PRC 97 (2018) 034901

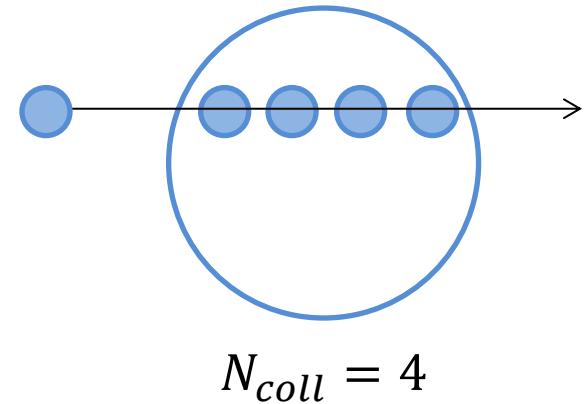
Outline

- wounded nucleons, quarks
- wounded nucleon/quark emission function
- PHENIX data on $dN/d\eta$
- forward-backward correlations
- longitudinal fluctuations and correlations
- conclusions

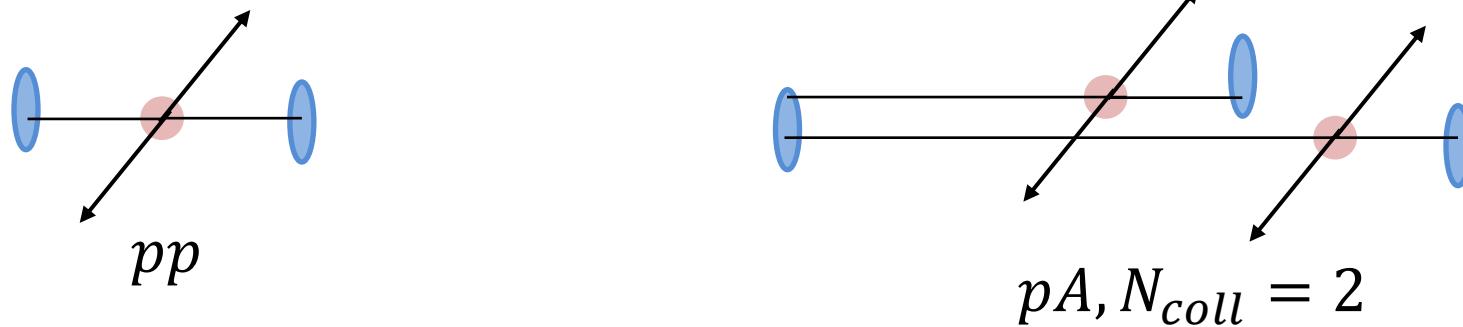
p+A collisions: Two simplest models

Number of collisions scaling:

$$\langle N_{pA} \rangle = \frac{\langle N_{pp} \rangle}{1} N_{coll}$$



Easy to understand in QCD



It works very well for high p_t particles, but not for low p_t

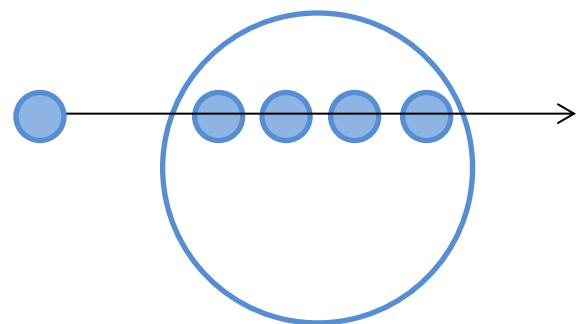
Wounded Nucleon Model (WNM)

A.Bialas, M.Bleszynski, W.Czyz,
Nucl. Phys. B 111, 461 (1976)

Number of “sources” scaling

At $y = 0$ or for the total number of particles:

$$\langle N_{pA} \rangle = \frac{\langle N_{pp} \rangle}{2} N_{part}$$



$$N_{part} = 4 + 1$$

$$N_{coll} = 4$$

Not clear how to understand it in QCD

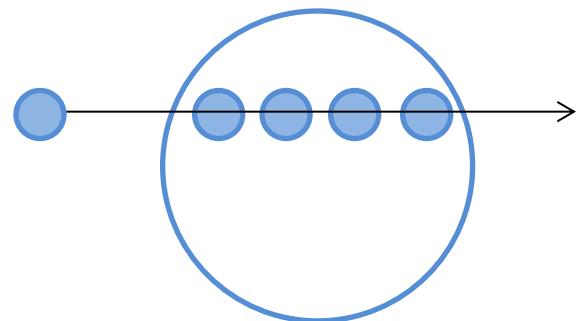
The model works very well in the non-perturbative region for 200 GeV d+Au collisions at RHIC (and for smaller energies in various p+X collisions).

Wounded Nucleon Model (WNM)

A.Bialas, M.Bleszynski, W.Czyz,
Nucl. Phys. B 111, 461 (1976)

Here each wounded nucleon produces on average $\langle N_{pp} \rangle / 2$ independently on the number of collisions

$$\langle N_{pA} \rangle = \frac{\langle N_{pp} \rangle}{2} N_{part}$$



$$N_{part} = 4 + 1$$
$$N_{coll} = 4$$

Model fails in A+A collisions. Almost all nucleons collide many times.
Scaling with the number of wounded quarks (quarks-diquarks)

$$\langle N_{AA} \rangle \propto N_{quark}$$

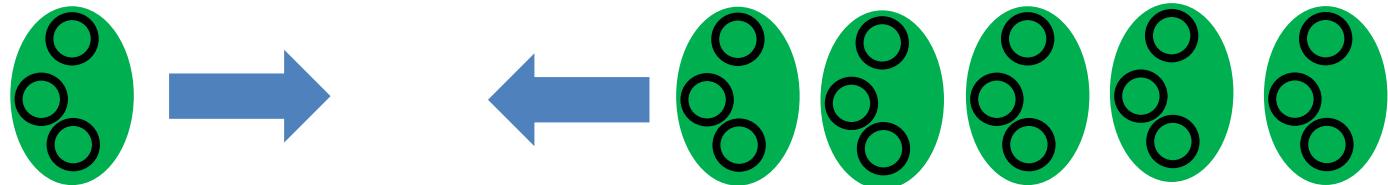
coefficient from pp

Each wounded quark produces particles independently on the number of collisions

Particle production from wounded nucleon depends on the number of collisions



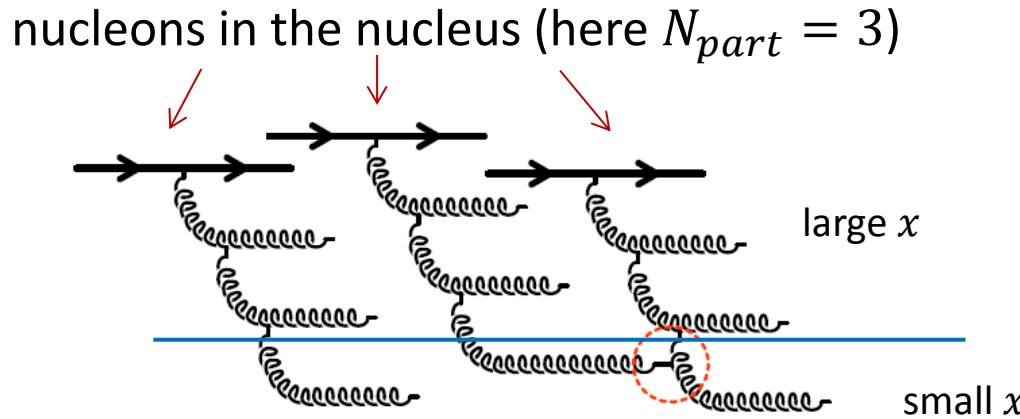
~1.5 wounded
quarks



~3 wounded
quarks

CGC for example, gives something different

A.Dumitru, L.McLerran,
NPA 700 (2002) 492



Number of large- x partons is proportional to N_{part}

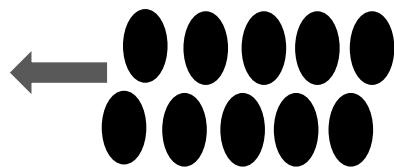
Number of low- x gluons (saturation) do not scale with N_{part}
since we are in the nonlinear regime

$$\langle N_{pA} \rangle \sim \ln(N_{part})$$

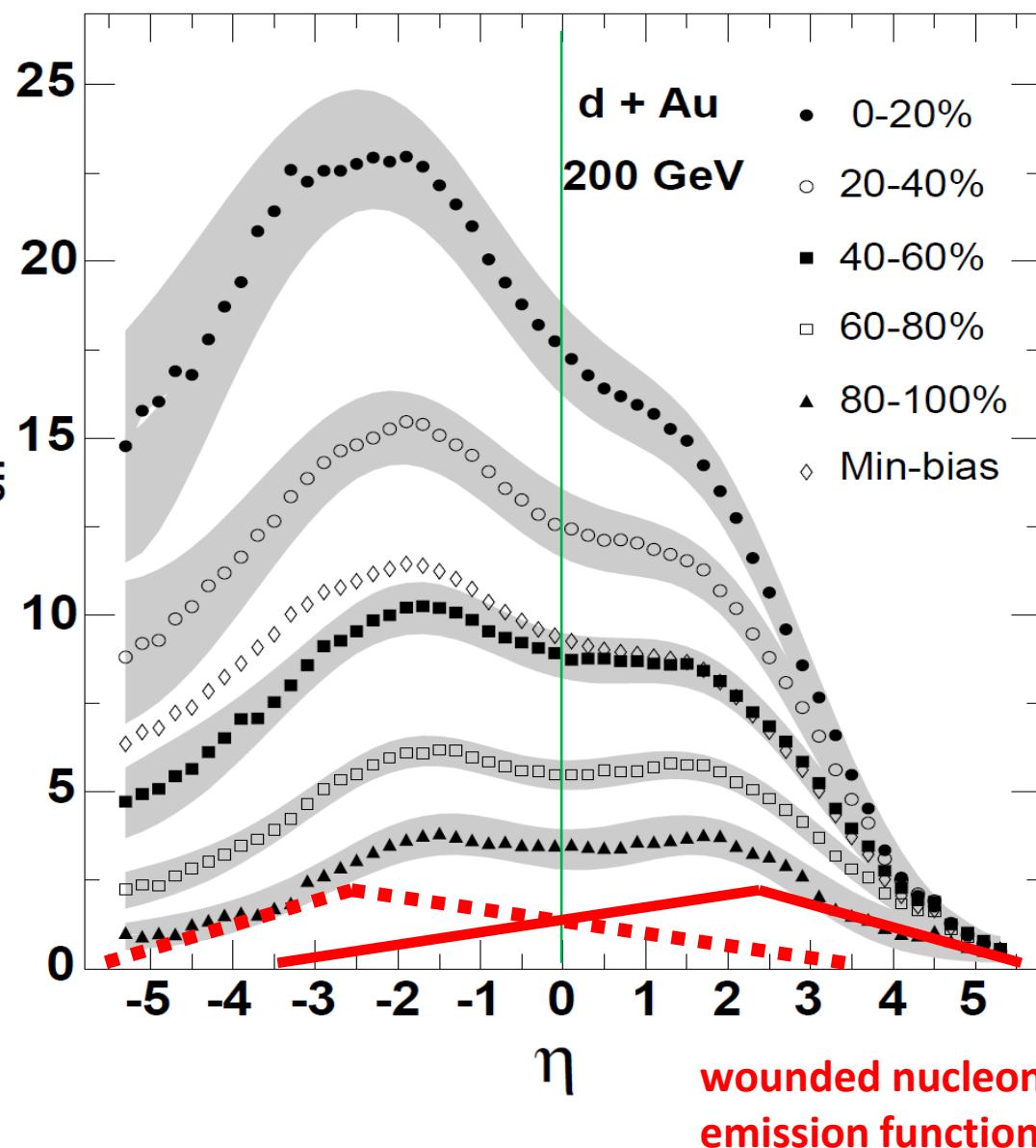
hard to test in pA
 N_{part} not measured

PHOBOS d+Au

central

 $dN_{cn}/d\eta$

peripheral



Wounded nucleon (quark) model

A.Bialas, W.Czyz
APPB 36 (2005) 905

$$\frac{dN}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

if $w_L - w_R \neq 0$

$w_{L,R}$ – number of left- and right-going constituents

$$F(\eta) = \frac{1}{2} \left[\frac{N(\eta) + N(-\eta)}{w_L + w_R} + \frac{N(\eta) - N(-\eta)}{w_L - w_R} \right]$$

↑
wounded source
emission function

$$N(\eta) \equiv \frac{dN}{d\eta}$$

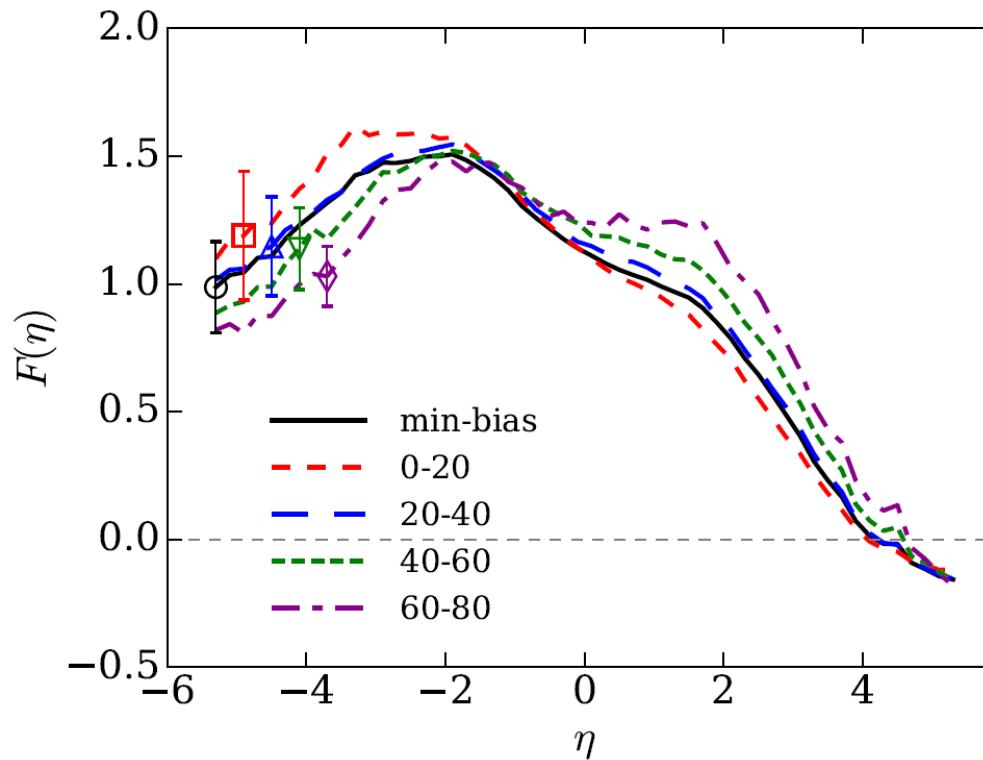
Procedure:

- nucleon and quark Glauber model
- in each event we have N_{part} and N_{quark}
- particles produced according to negative binomial distribution
- cuts on centrality
- w_L and w_R (nucleons and quarks) at different centralities
- calculate $F(\eta)$ for different centralities using d+Au data

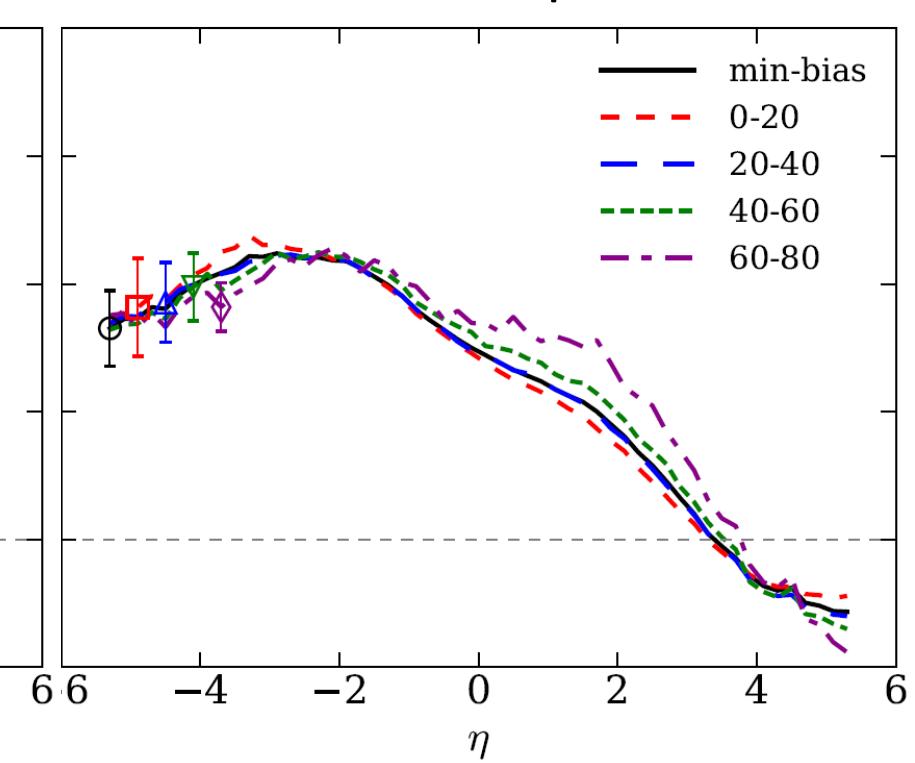
Wounded nucleon and quark emission functions

$\sqrt{s} = 200 \text{ GeV}$

wounded nucleons

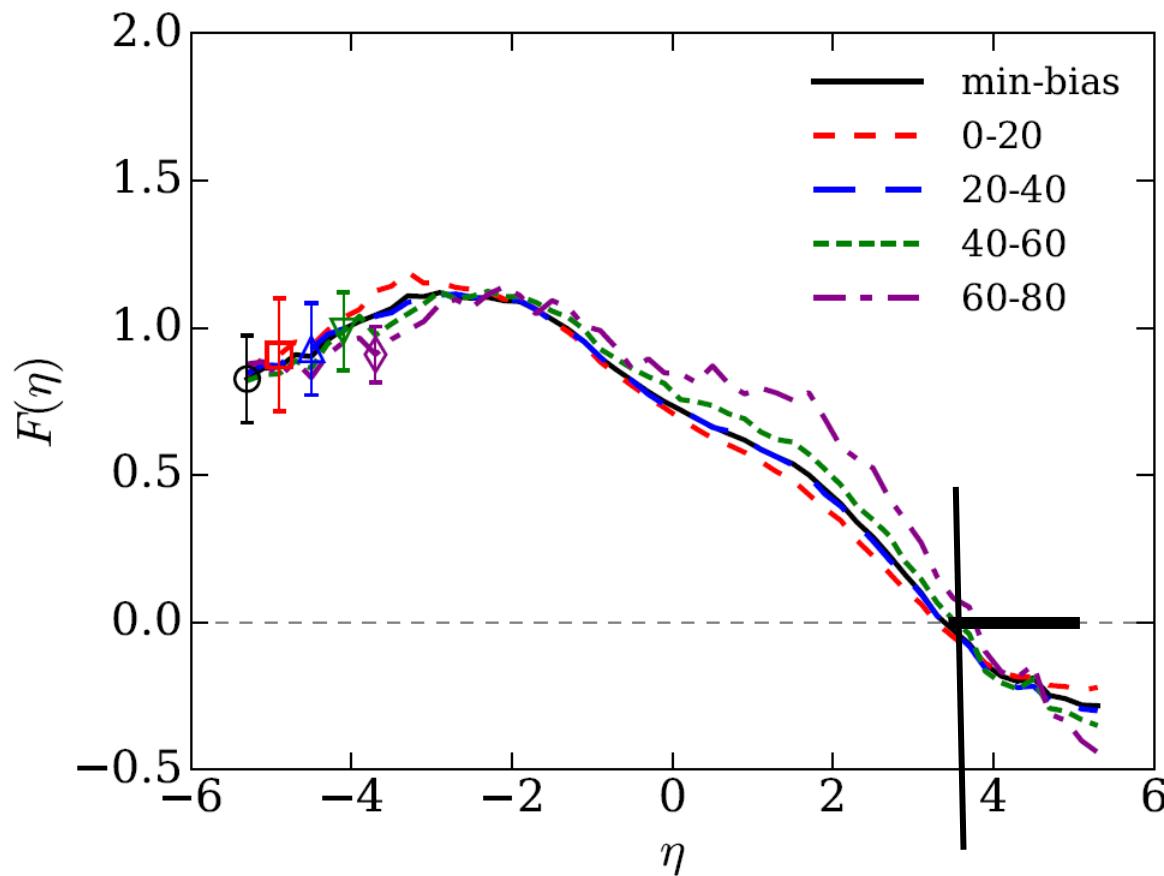


wounded quarks



close to $\eta = 0, F(\eta) \sim \eta$

Wounded quark emission function



model fails in the fragmentation
region (as it should)

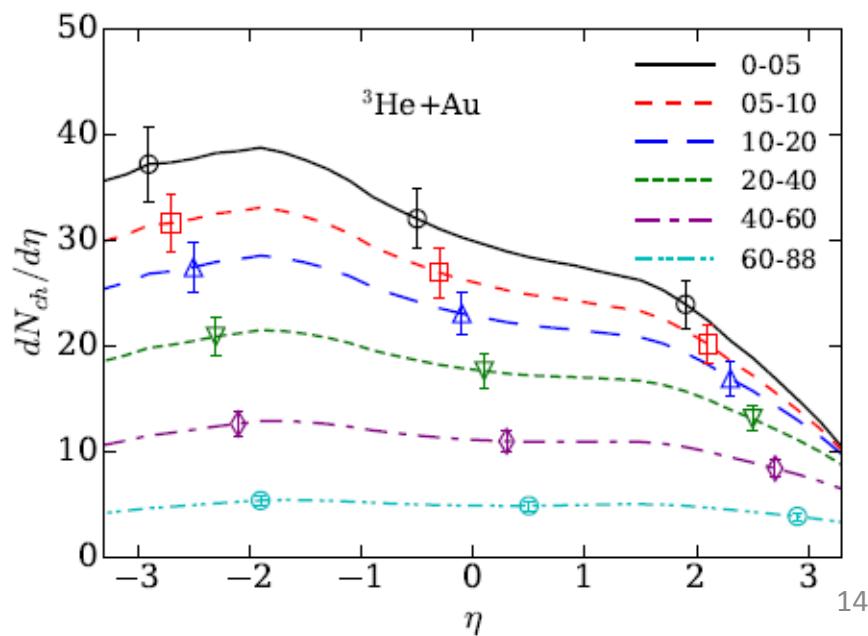
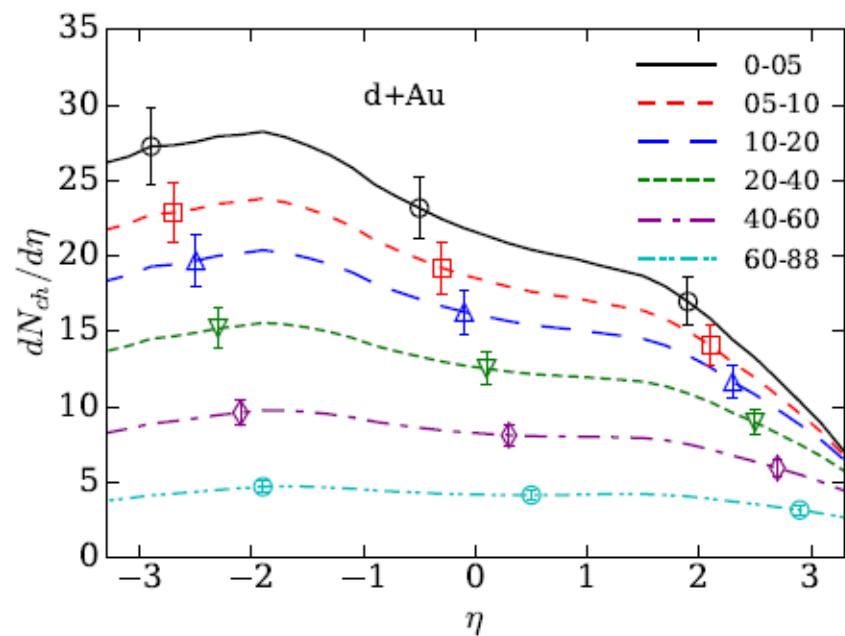
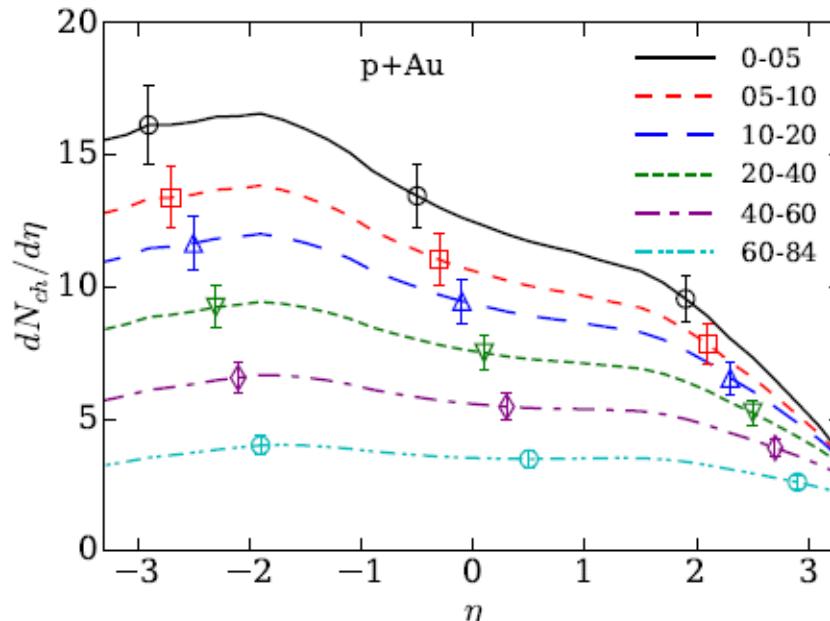
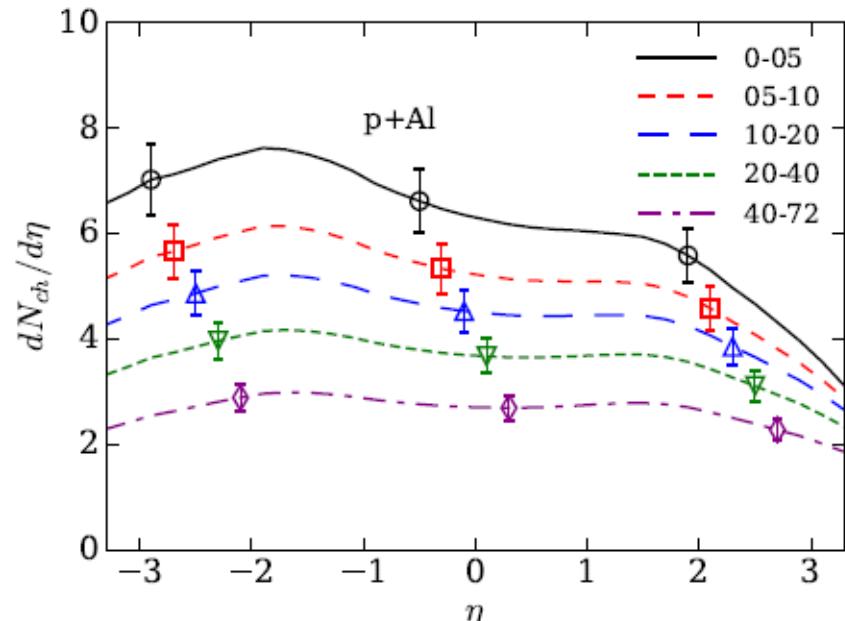
PHENIX request: Predictions for p+Al, p+Au, d+Au, He3+Au

Procedure:

- take the wounded quark emission function from min-bias d+Au
- quark Glauber model for p+Al, p+Au, d+Au, He3+Au
- **parameter-free** predictions for $dN/d\eta$ in all systems

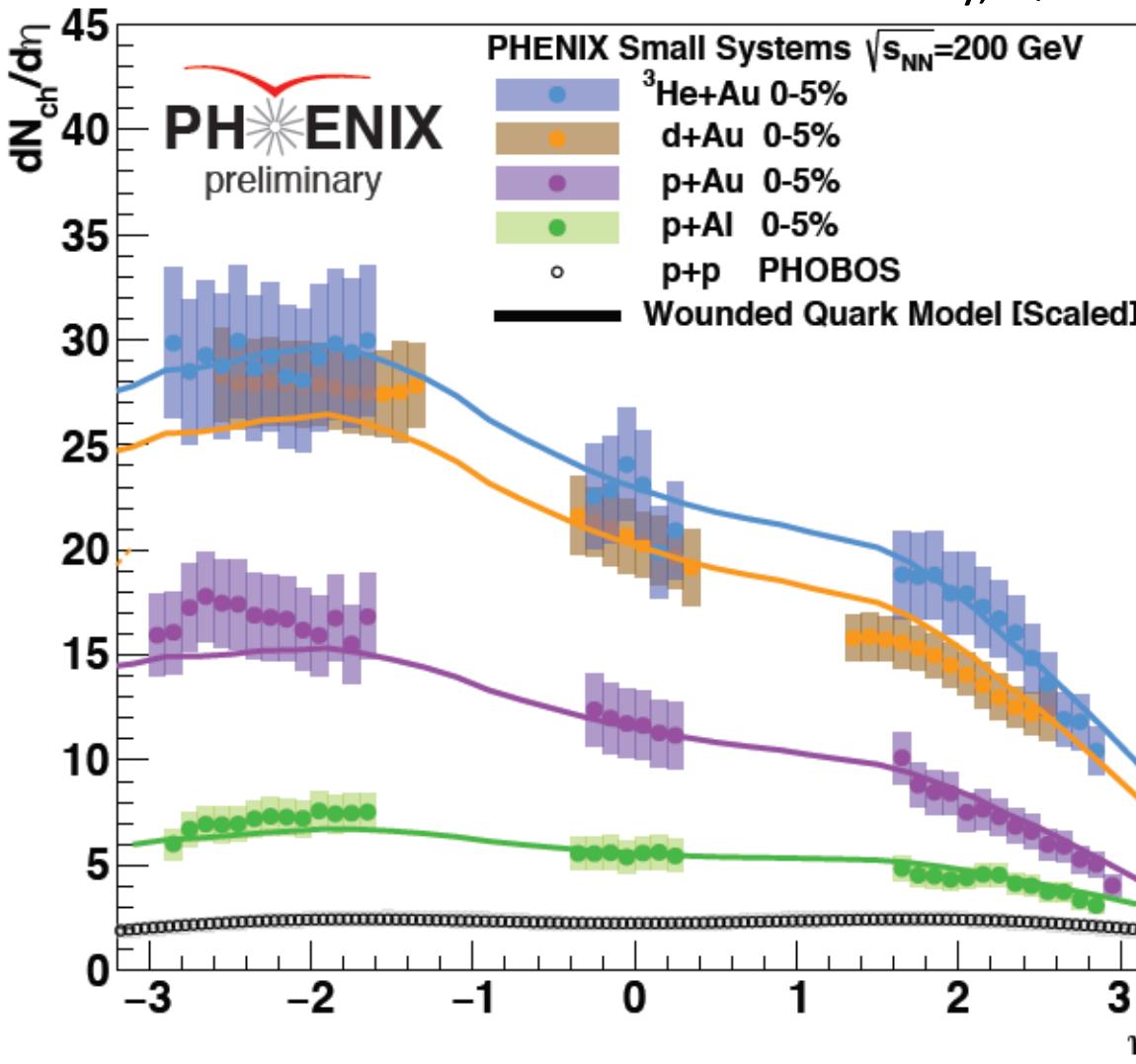
very simple model,
no free parameters,
expected accuracy? (20% ?)

PHENIX request (based on min-bias quark emission function)



PHENIX results: All systems in central collisions

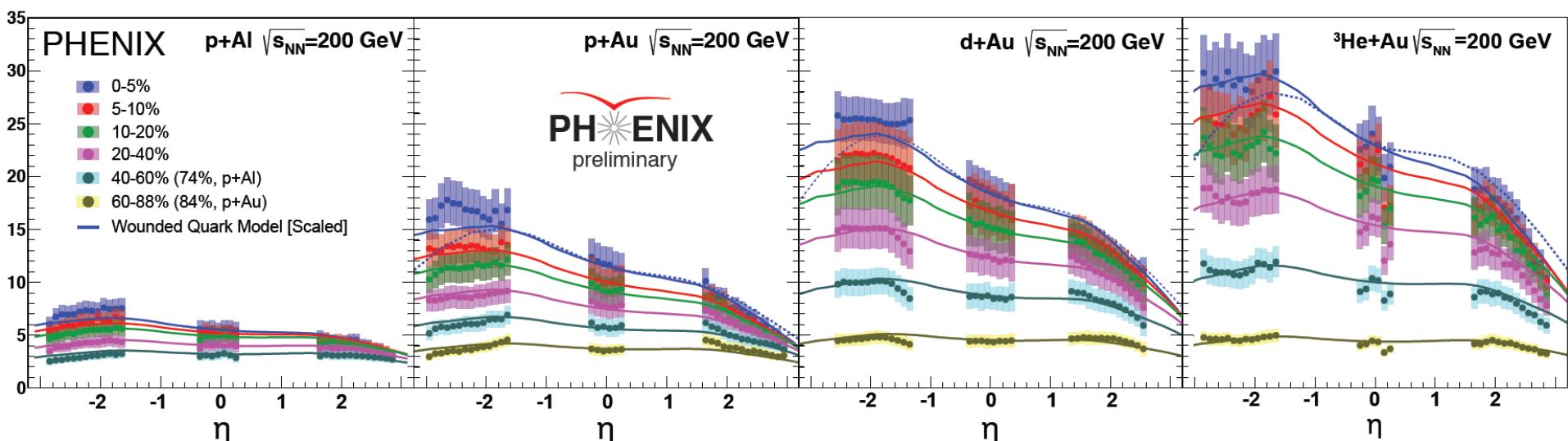
D. McGlinchey, QM18



scaled

All systems and all centralities

D. McGlinchey, QM18

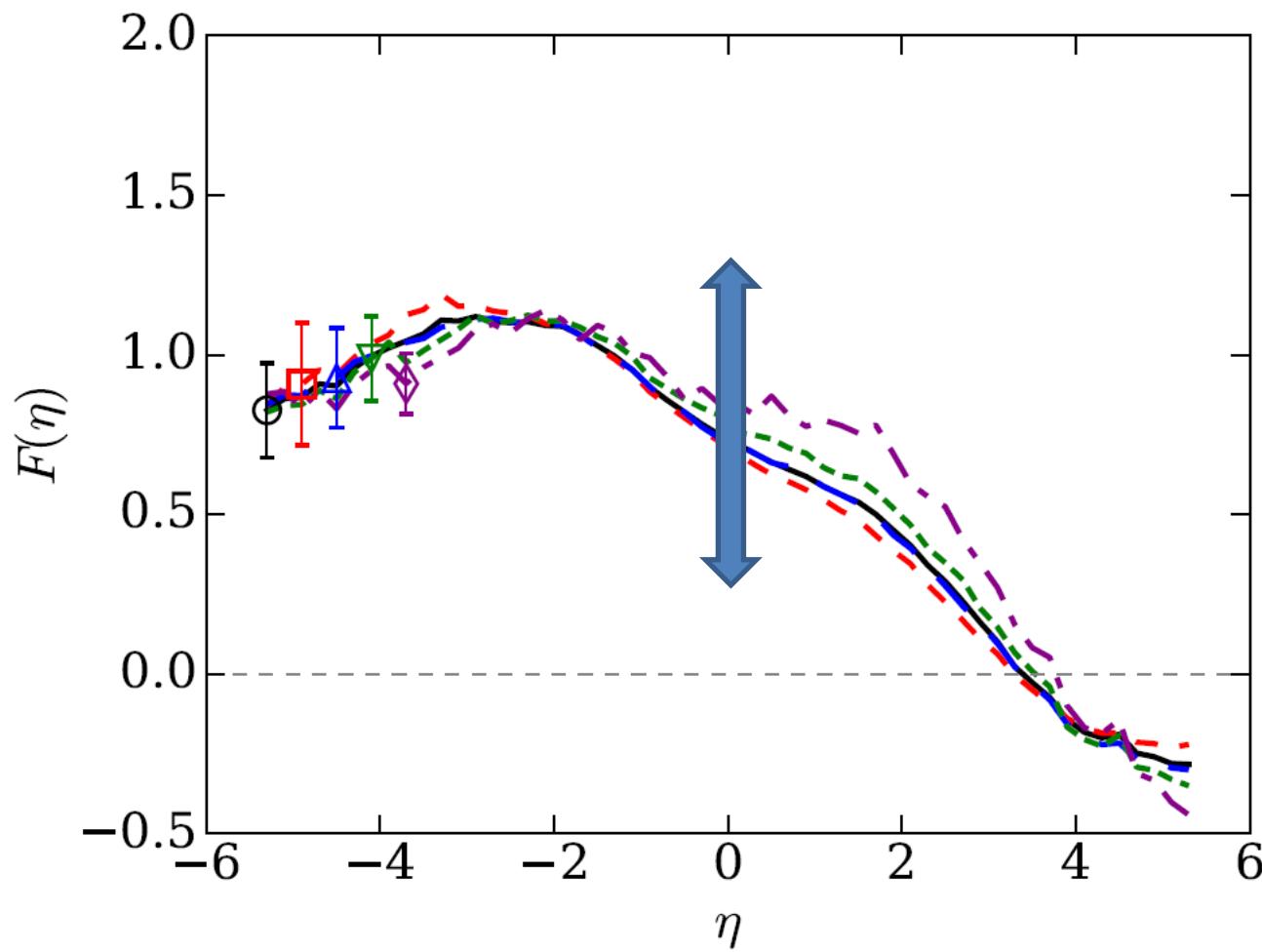


Common wounded quark emission function describes the shape of $dN/d\eta$ for all systems and centralities reasonably well

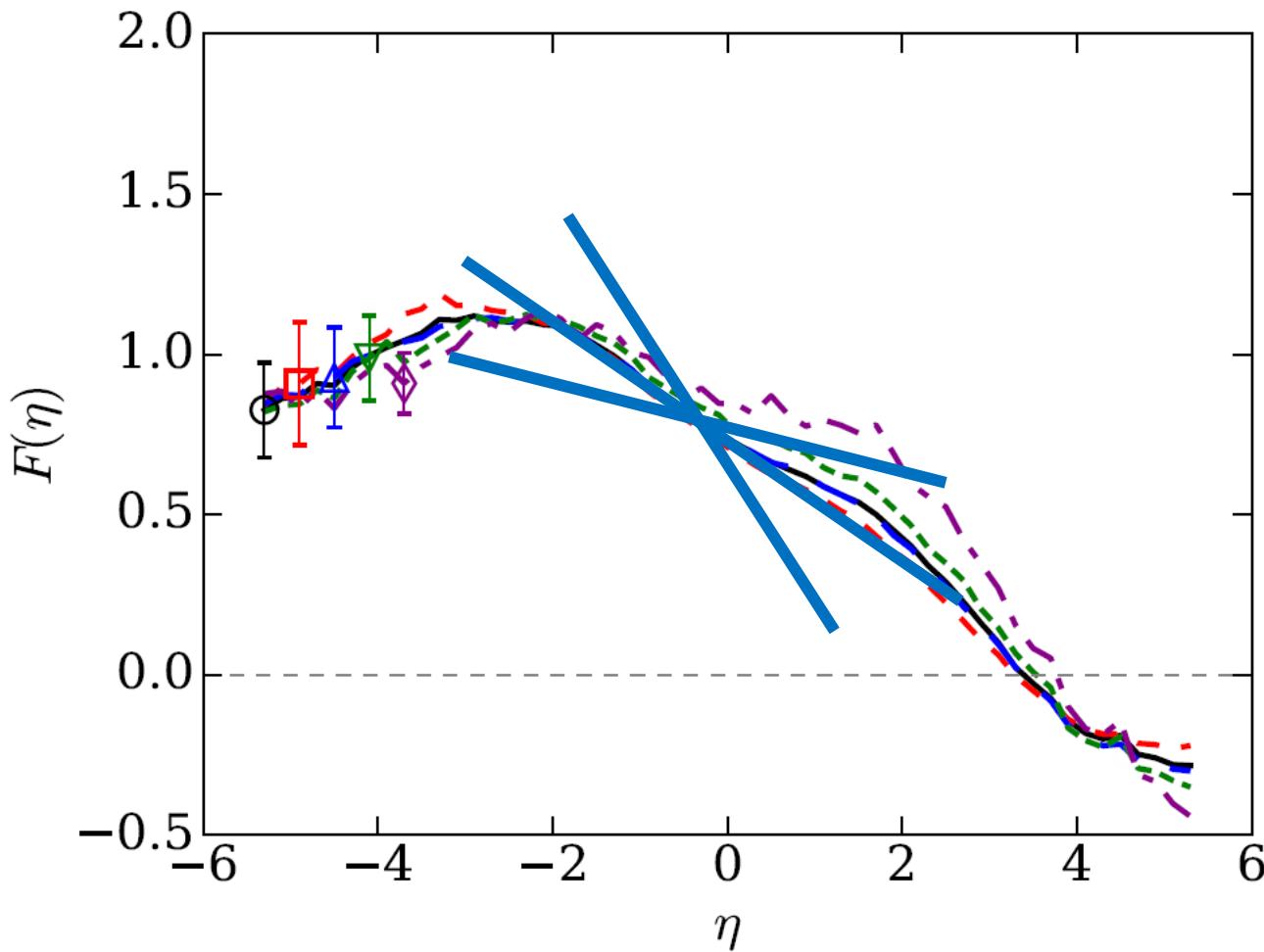
CGC predictions are welcomed

Next step: Fluctuation and correlations. Needed, e.g., for hydro initial conditions

Known part: Multiplicity fluctuations

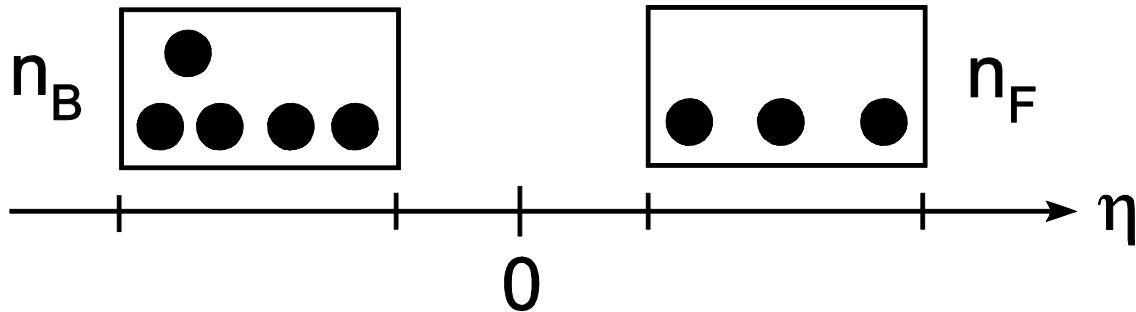


Unknown part: Slope fluctuations



We can learn directly from long-range correlations

Forward-backward multiplicity correlations



$$b = \frac{\langle n_B n_F \rangle - \langle n_B \rangle^2}{\langle n_B^2 \rangle - \langle n_B \rangle^2}$$

$b = 1$, maximum correlation

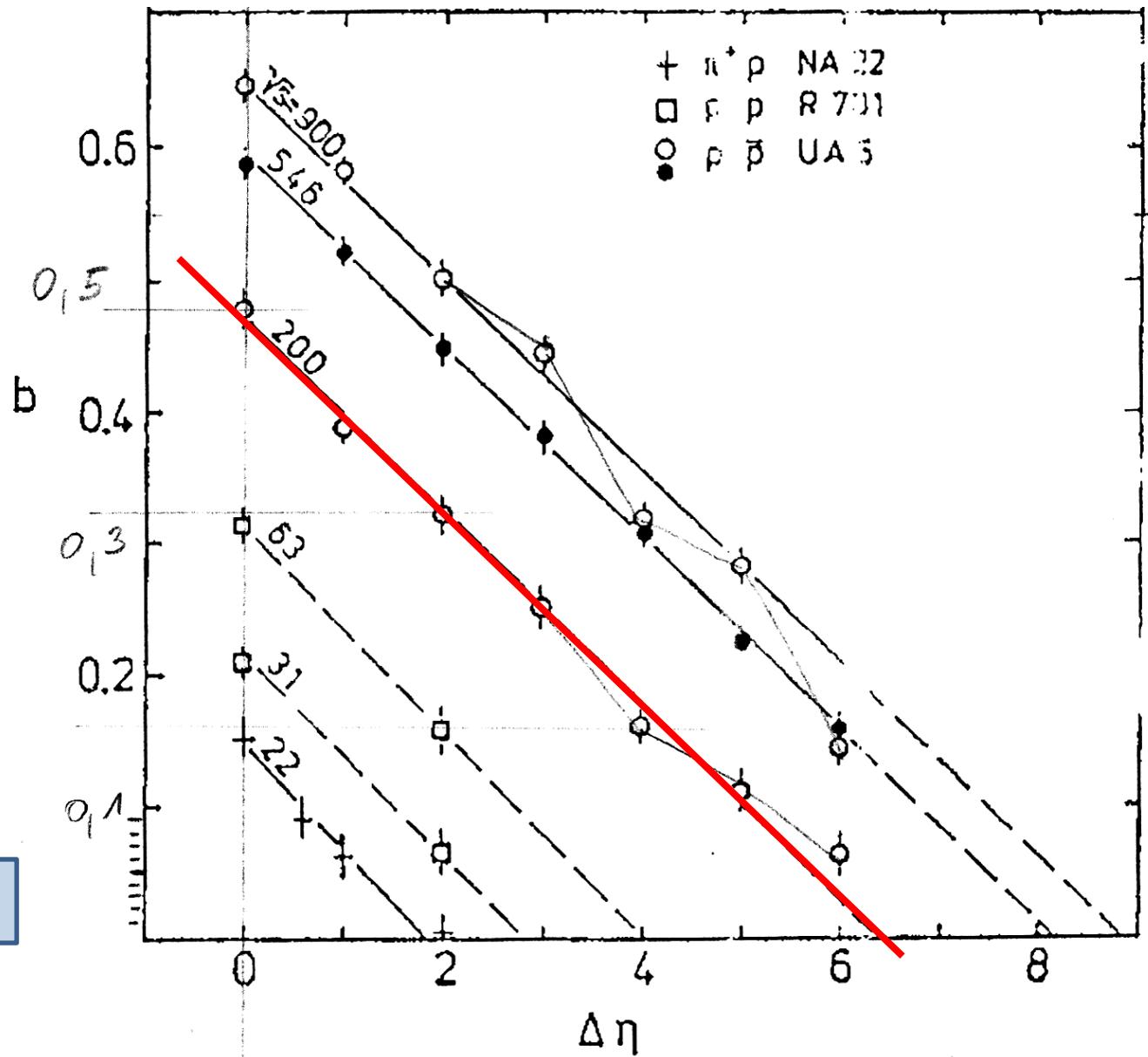
$b = 0$, no correlation

$b = -1$, maximum anticorrelation

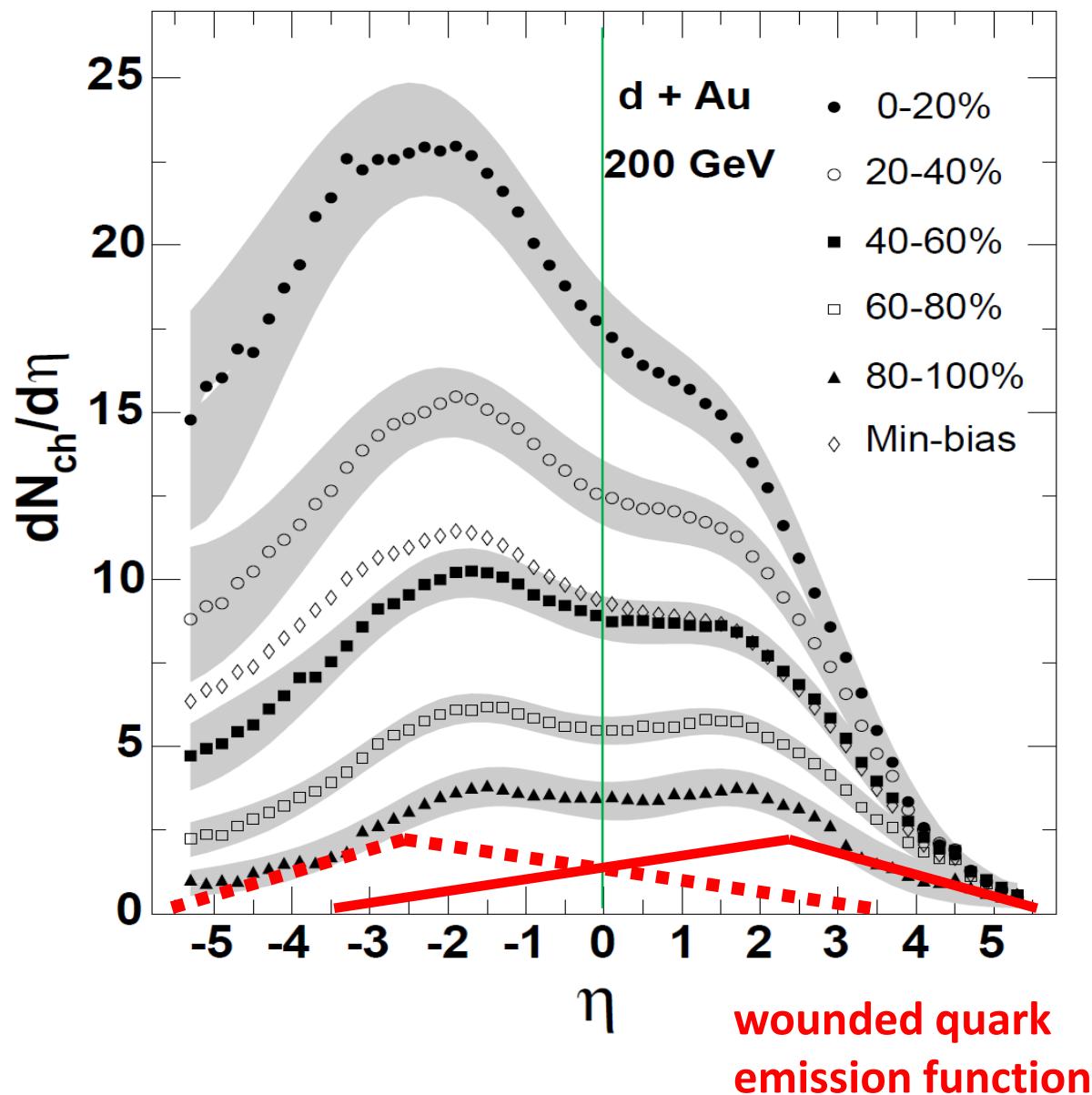
correlation
coefficient b
for various
energies
and rapidity
separations
 $\Delta\eta$ between
bins B and F



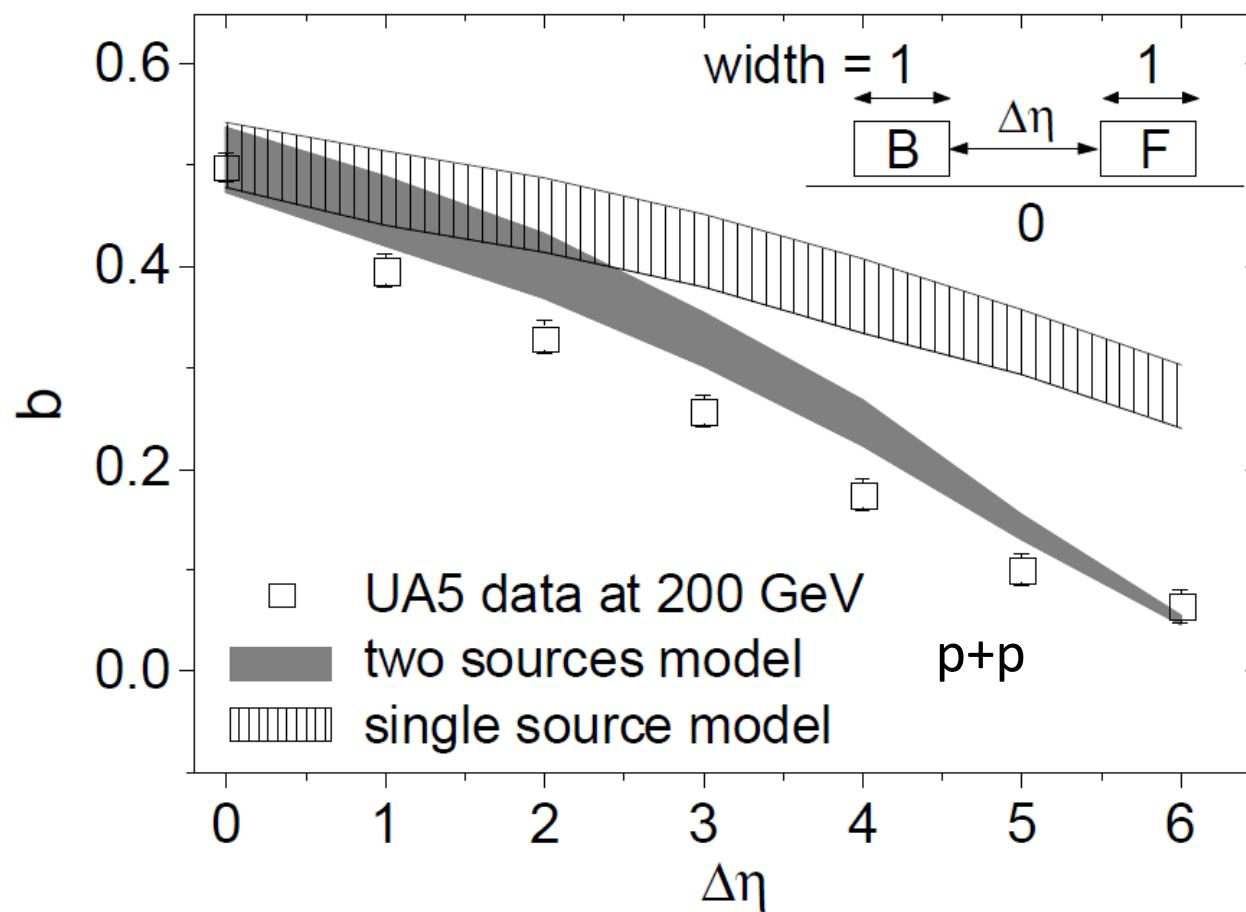
$\Delta\eta|_{max} \approx 10$
at 200 GeV



PHOBOS d+Au



Forward-backward multiplicity correlation in p+p



Rapidity correlations

$$\rho_{\text{event}}(y) = \langle \rho(y) \rangle \left[1 + a_0 + a_1 \frac{y}{Y} + \dots \right]$$

↑
single particle distribution
in an event (neglecting
statistical fluctuations)

↑
average single
particle distribution

a_0 is rapidity independent fluctuation of fireball as a whole
multiplicity distribution

a_1 is an event-by-event rapidity asymmetry

e.g. asymmetry in the number of left- and right-going constituents (nucleons, quarks, diquarks, etc.) in p+p, p+A and A+A

Y - measurement is from $-Y$ to Y

A.Bialas, AB, K.Zalewski,
PLB 710 (2012) 332

Long (and short) range rapidity correlations

$$\frac{C_2(y_1, y_2)}{\langle \rho(y_1) \rangle \langle \rho(y_2) \rangle} \sim \langle a_0^2 \rangle + \langle a_1^2 \rangle \frac{y_1 y_2}{Y^2} + \dots$$

orthogonal
polynomials

$\langle a_1^2 \rangle$ has a trivial contribution from $\langle (w_L - w_R)^2 \rangle$

It is also sensitive to slope fluctuation

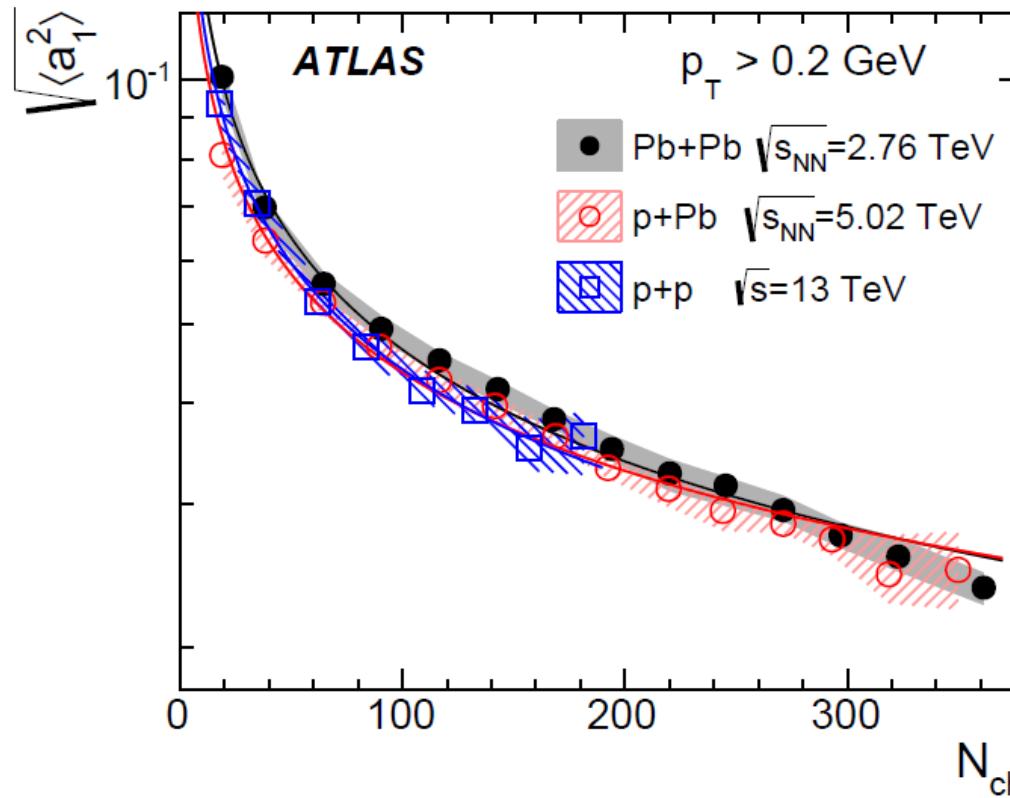
The ATLAS Collaboration

Abstract

Two-particle pseudorapidity correlations are measured in $\sqrt{s_{\text{NN}}} = 2.76$ TeV Pb+Pb, $\sqrt{s_{\text{NN}}} = 5.02$ TeV $p+\text{Pb}$, and $\sqrt{s} = 13$ TeV pp collisions at the LHC, with total integrated luminosities of approximately $7 \mu\text{b}^{-1}$, 28 nb^{-1} , and 65 nb^{-1} , respectively. The correlation function $C_N(\eta_1, \eta_2)$ is measured as a function of event multiplicity using charged particles in the pseudorapidity range $|\eta| < 2.4$. The correlation function contains a significant short-range component, which is estimated and subtracted. After removal of the short-range component, the shape of the correlation function is described approximately by $1 + \langle a_1^2 \rangle \eta_1 \eta_2$ in all collision systems over the full multiplicity range. The values of $\sqrt{\langle a_1^2 \rangle}$ are consistent between the opposite-charge pairs and same-charge pairs, and for the three collision systems at similar multiplicity. The values of $\sqrt{\langle a_1^2 \rangle}$ and the magnitude of the short-range component both follow a power-law dependence on the event multiplicity. The η distribution of the short-range component, after symmetrizing the proton and lead directions in $p+\text{Pb}$ collisions, is found to be smaller than that in pp collisions with comparable multiplicity.

a_1 as a function of the number of produced particles in $|\eta| < 2.5$ and $p_t > 0.2$ GeV.

PRC 95, 064914 (2017)



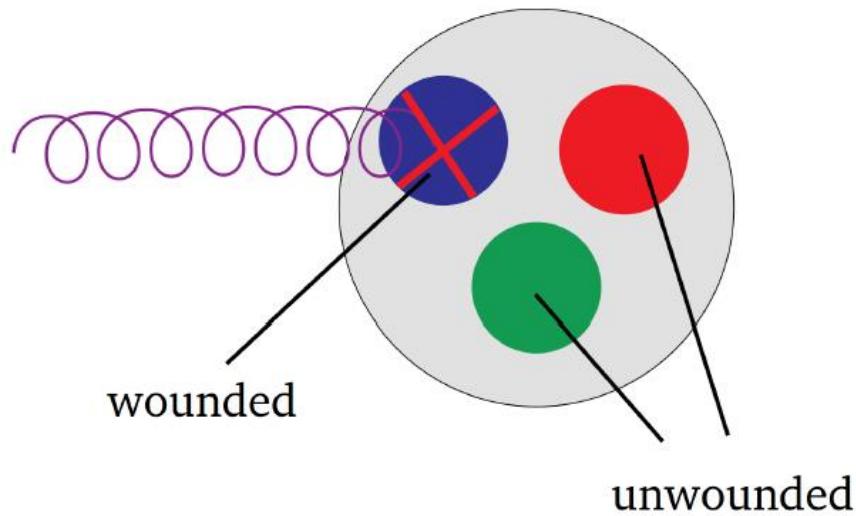
$$\sqrt{\langle a_1^2 \rangle} \sim \frac{1}{N_{\text{ch}}^{0.5}}$$

Particle sources and their fluctuations seem to be similar in peripheral Pb+Pb, min-bias p+Pb and central p+p.

Indication of universal slope fluctuations - work in progress

Next steps (all in progress):

- slope fluctuation
- wounded quark emission function at different energies (LHC, PHENIX)
- unwounded quarks (in wounded nucleons)
- A+A collisions
- microscopic description of $F(\eta)$



Conclusions

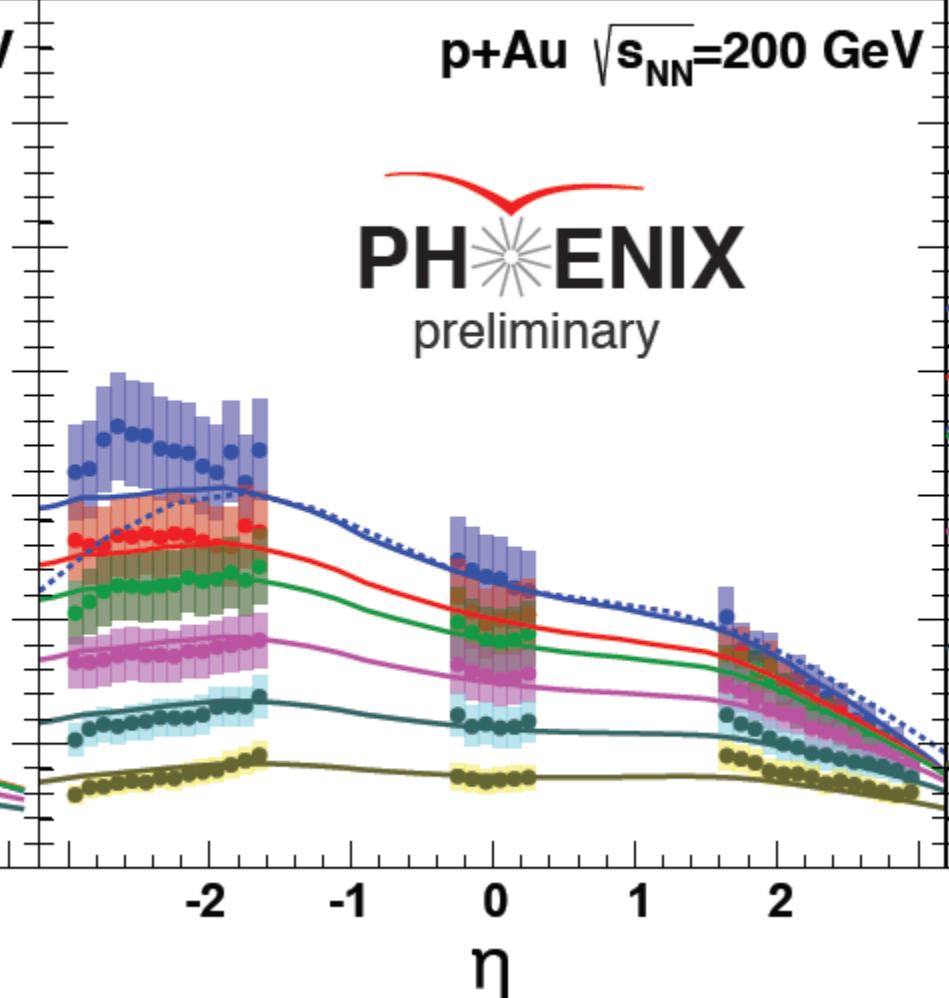
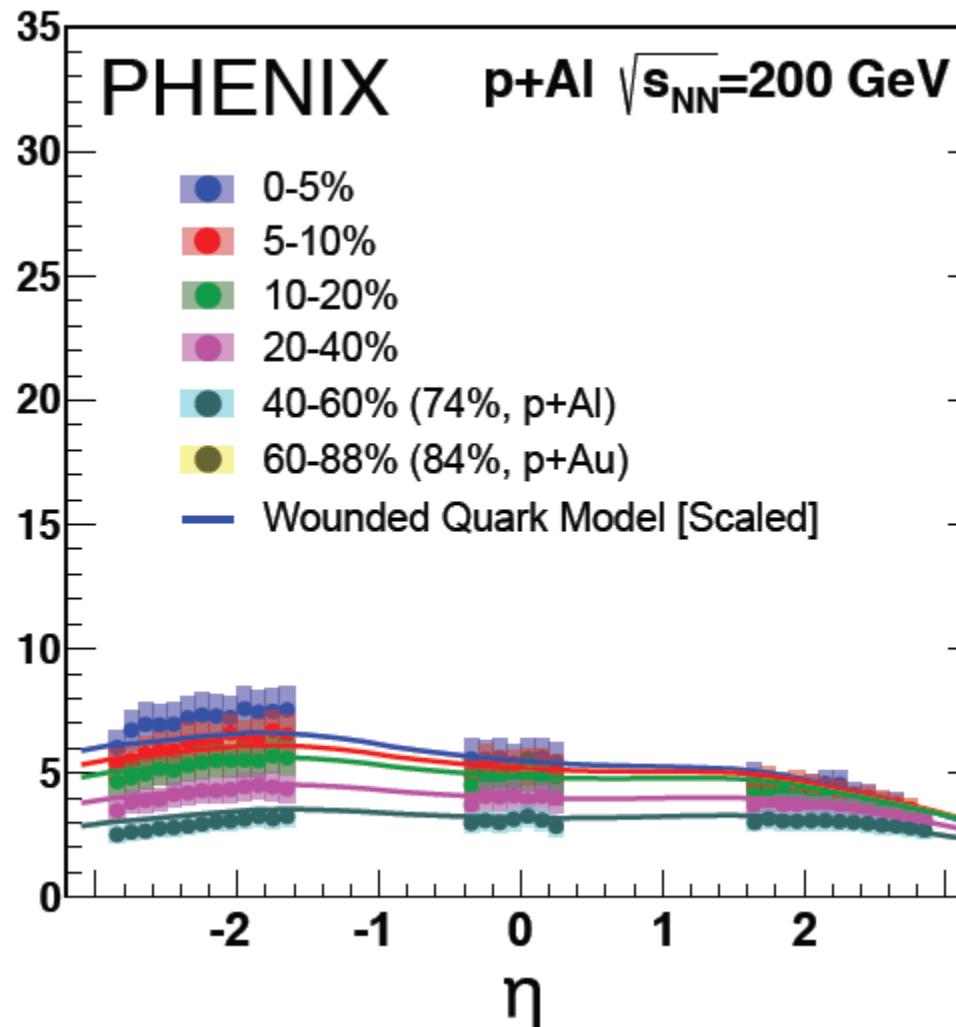
Possible universality of wounded quark emission function

Good description of PHENIX data on p+Al, p+Au, d+Au, He3+Au.
No free parameters

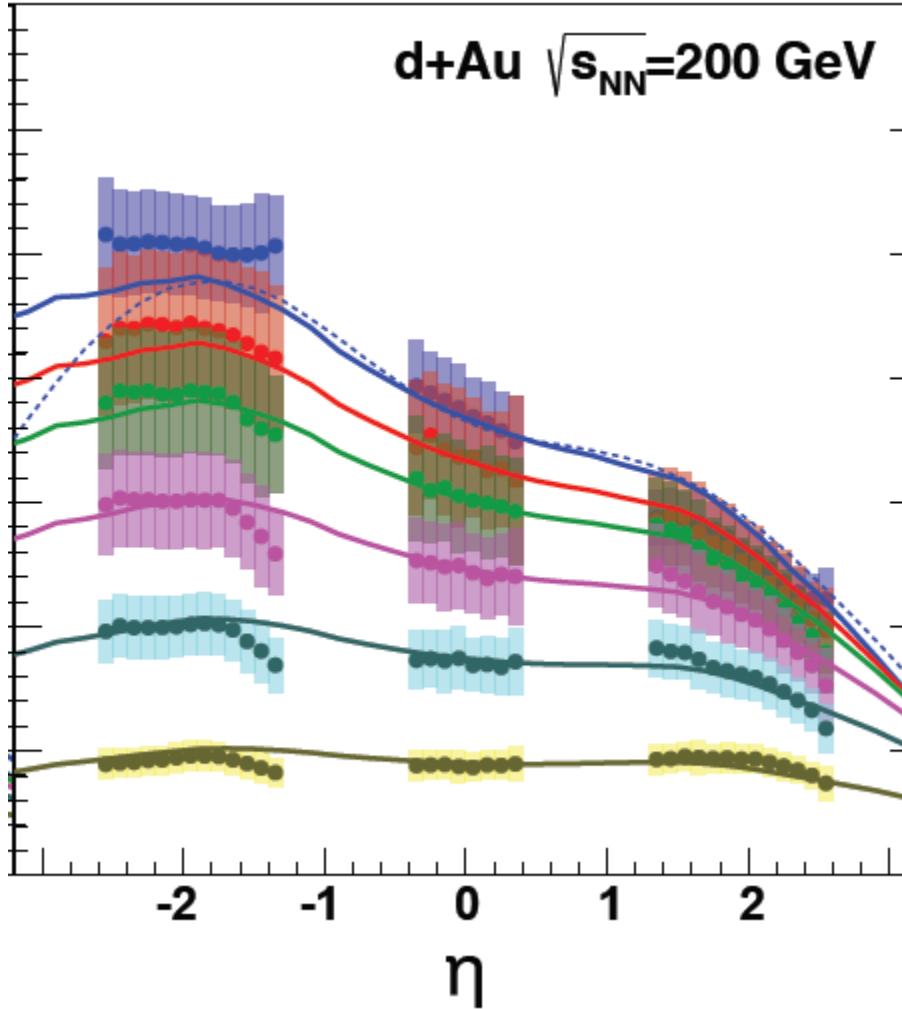
Consistent with forward-backward rapidity correlation

Possibly universal slope fluctuations from long-range rapidity correlations

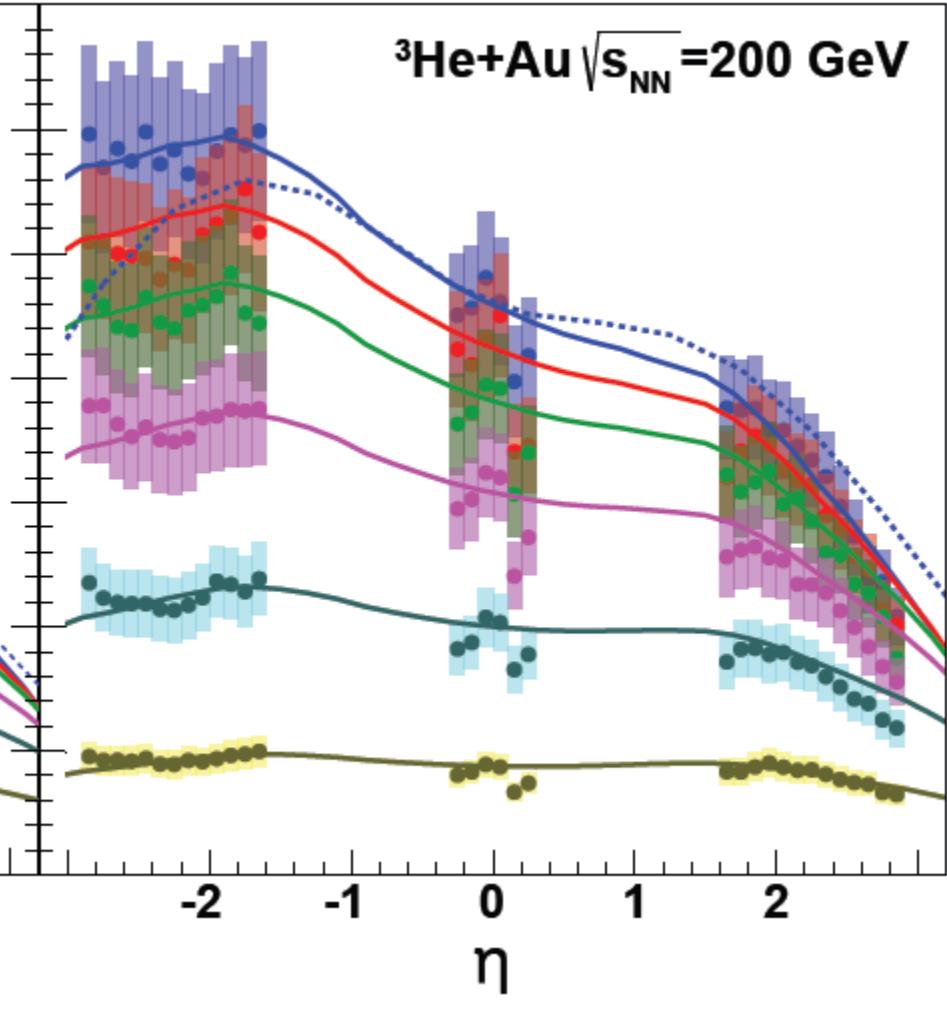
Backup



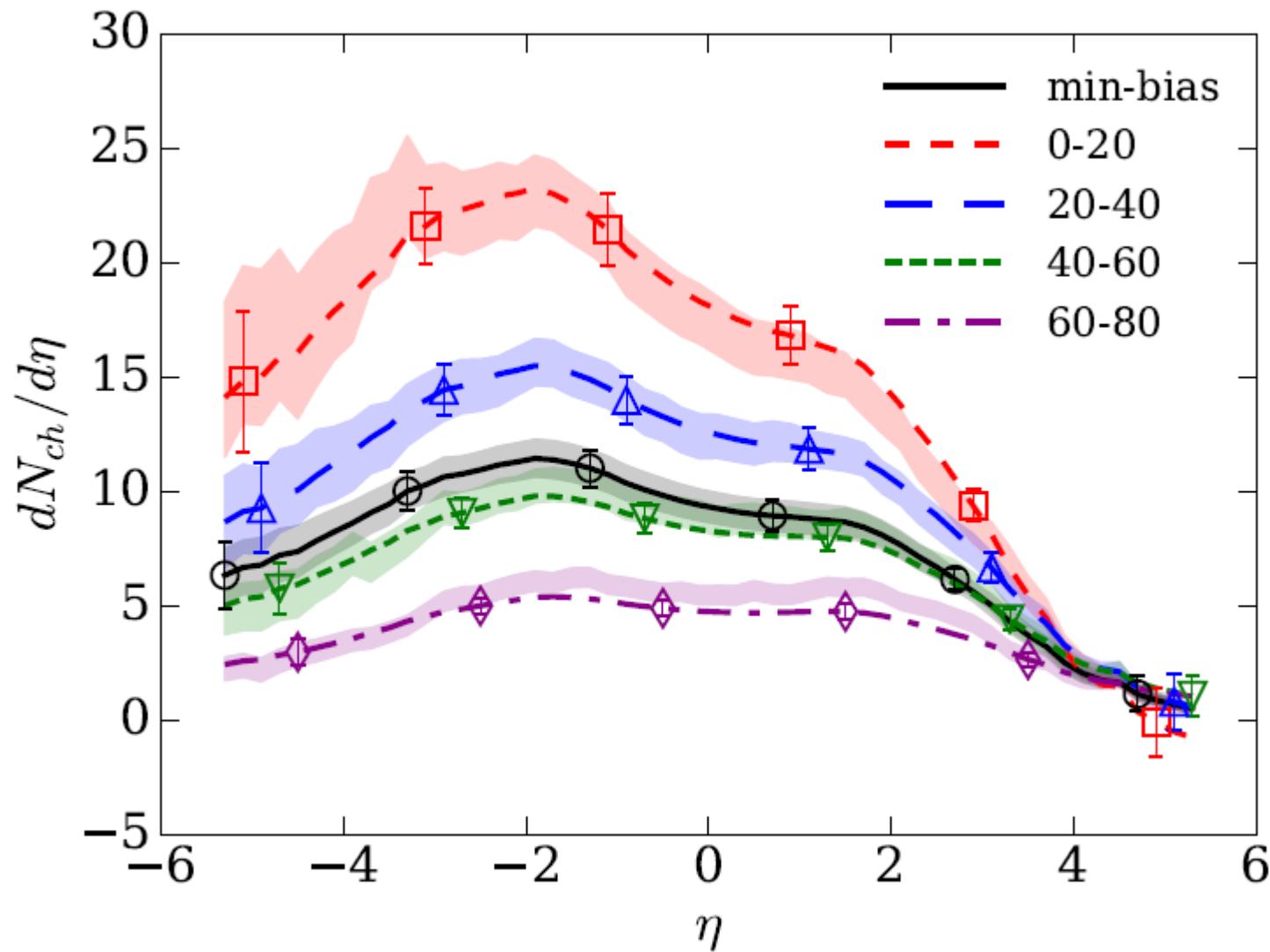
d+Au $\sqrt{s_{NN}}=200$ GeV



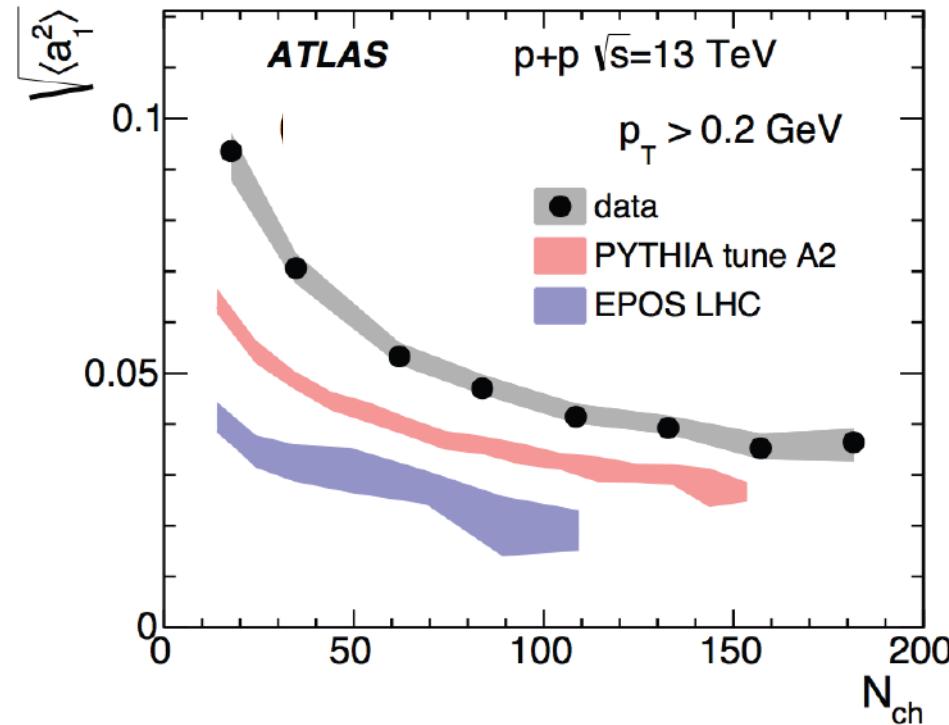
$^3\text{He}+\text{Au}$ $\sqrt{s_{NN}}=200$ GeV



PHOBOS d+Au from min-bias quark emission function



PYTHIA and EPOS vs p+p data



taken from
Jiangyong Jia (QM17)

Related papers:

- J.Jia, S.Radhakrishnan , M.Zhou, PRC 93, 044905 (2016)
- P.Bożek, W.Broniowski, A.Olszewski, PRC 92 (2015) 5, 054913
- A.Monnai, B.Schenke, PLB 752 (2016) 317
- B.Schenke, S.Schlichting, PRC 94, 044907 (2016)
- P.Bożek, W.Broniowski, PRC 93, 064910 (2016)
- R.He, J.Qian, L.Huo, 1702.03137
- W.Ke, J.Moreland, J.Bernhard, S.Bass, 1610.08490

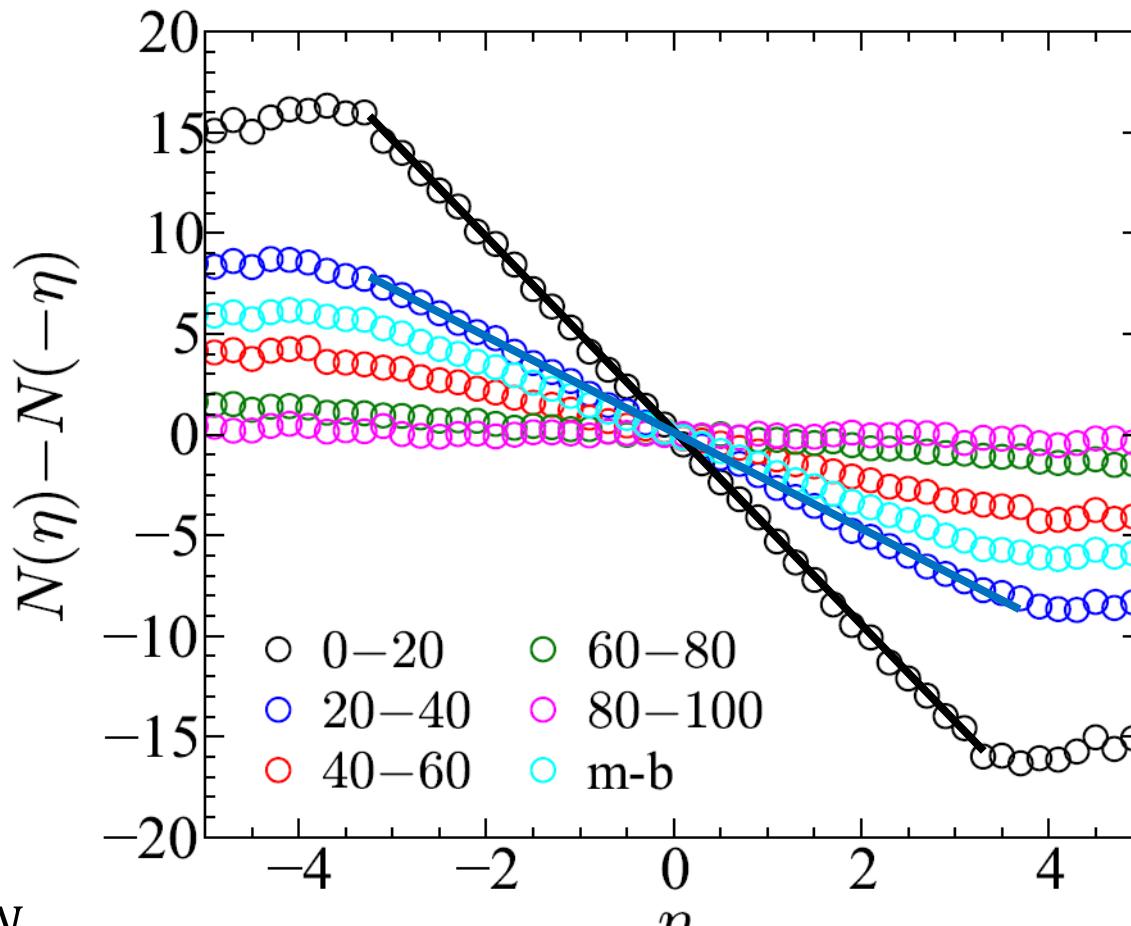
For example the genuine 4 and 6-particle correlation functions

$$\frac{C_4(y_1, \dots, y_4)}{\langle \rho(y_1) \rangle \dots \langle \rho(y_4) \rangle} = \dots + [\langle a_1^4 \rangle - 3\langle a_1^2 \rangle^2] \frac{y_1 y_2 y_3 y_4}{Y^4} + \dots$$

$$\frac{C_6}{\langle \rho \rangle \dots \langle \rho \rangle} = \dots + [\langle a_1^6 \rangle - 15\langle a_1^2 \rangle \langle a_1^4 \rangle - 10\langle a_1^3 \rangle^2 + 30\langle a_1^2 \rangle^3] \frac{y_1 y_2 y_3 y_4 y_5 y_6}{Y^6} + \dots$$

Antisimetritzation of $N(\eta)$

PHOBOS d+Au



$$N(\eta) \equiv \frac{dN}{d\eta}$$

Similar technique for $p_t - p_t$ correlations

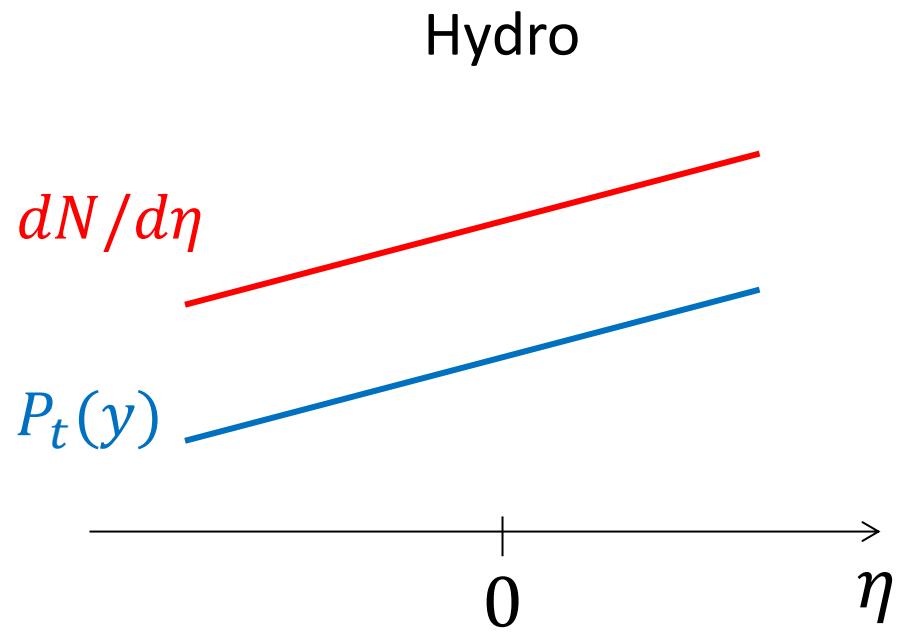
$$P_t(y) = \frac{1}{N} \sum_{i=1}^N p_t^{(i)}, \quad \text{average } p_t \text{ in an event}$$

$$\frac{P_t(y)}{\langle P_t(y) \rangle} = 1 + b_0 + b_1 y + \dots,$$

$$\frac{C_{[P,P]}(y_1, y_2)}{\langle P_t(y_1) \rangle \langle P_t(y_2) \rangle} = \langle b_0^2 \rangle + \underline{\langle b_1^2 \rangle} y_1 y_2 + \dots,$$

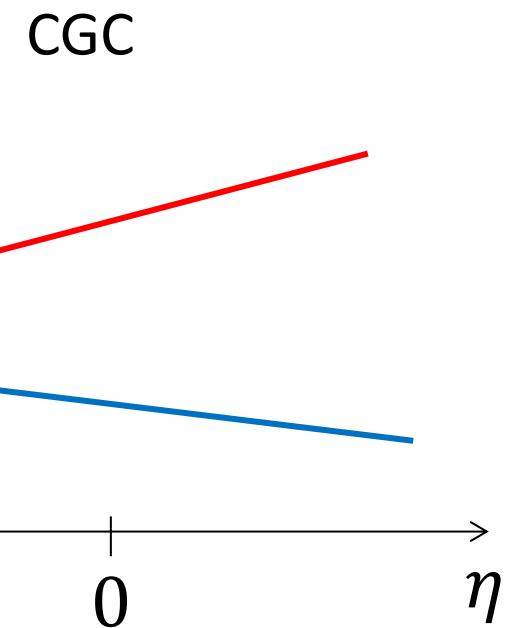
$$C_{[P,P]}(y_1, y_2) \equiv \langle P_t(y_1) P_t(y_2) \rangle - \langle P_t(y_1) \rangle \langle P_t(y_2) \rangle.$$

or more interesting $N - p_t$ correlations



$$a_1 > 0, b_1 > 0$$

$$\langle a_1 b_1 \rangle > 0$$



$$a_1 > 0, b_1 < 0$$

$$\langle a_1 b_1 \rangle < 0$$

P.Bozek, AB, V.Skokov, PLB 728 (2014) 662

K.Deja, K.Kutak, PRD 95 (2017), 114027

F.Duraes, A.Giannini, V.Goncalves, F.Navarra, PRC 94, 024917 (2016) [different CGC conclusion]

Rapidity $N - p_t$ correlations

$$C_{[N,P]}(y_1, y_2) \equiv \langle N(y_1) P_t(y_2) \rangle - \langle N(y_1) \rangle \langle P_t(y_2) \rangle,$$

$$\frac{C_{[N,P]}(y_1, y_2)}{\langle N(y_1) \rangle \langle P_t(y_2) \rangle} = \langle a_0 b_0 \rangle + \underline{\langle a_1 b_1 \rangle} y_1 y_2 + \dots$$

In general

$$\frac{C_{[N,P]}(y_1, y_2)}{\langle N(y_1) \rangle \langle P_t(y_2) \rangle} = \sum_{i,k} \langle a_i b_i \rangle T_i(y_1) T_k(y_2),$$

In p+A collisions

CGC: $\langle N_{pA} \rangle \sim \ln(N_{part})$

WNM: $\langle N_{pA} \rangle \sim N_{part}$

